

# The distinction between star clusters and associations

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## ABSTRACT

In Galactic studies a distinction is made between (open) star clusters and associations. For barely resolved objects at a distance of several Mpc this distinction is not trivial to make. Here we provide an objective definition by comparing the age of the stars to the crossing time of nearby stellar agglomerates. We find that a satisfactory separation can be made where this ratio equals unity. Stellar agglomerates for which the age of the stars exceeds the crossing time are bound, and are referred to as star clusters. Alternatively, those for which the crossing time exceeds the stellar age are unbound and are referred to as associations. This definition is useful whenever reliable measurements for the mass, radius and age are available.

**Key words:** Galaxy: open clusters and associations: general – galaxies: star clusters – stars: formation

Star forming galaxies consist of field stars, associations and star clusters. The distinction between star clusters and associations is not clearly defined. Ambartsumian (1947) introduced the term association in reference to loose agglomerates and he pointed out in subsequent studies that it is unlikely that they are bound by their own gravity (see also Blaauw 1964). When objects are classified as associations, it is generally not known whether the origin of the classification (e.g. based on the binding energy) can be attributed to the process of formation or the evolution. It has been posed, and it is often quoted, that the majority of stars form in star clusters and that there is a high rate of early cluster disruption (e.g. Kroupa 1998; Lada & Lada 2003). But if the star formation process is hierarchical then only a small fraction of the newborn stars reside in agglomerates that satisfy the conditions necessary to be bound by self-gravity at formation (e.g. Elmegreen 2008; Bressert et al. 2010). When observational samples of star clusters are used to support either one of the above scenarios it is vital to know how star clusters are separated from associations. Here we provide a definition of the distinction between these two classes of stellar agglomerates.

We use the recent literature compilation of young massive clusters and associations of Portegies Zwart, McMillan & Gieles (2010, hereafter PZMG10). This sample consists of all stellar agglomerates found in the literature for which a value of the half-light radius  $R_{\text{eff}}$ , mass  $M$ , and age were determined. Their sample contains 105 agglomerates with  $M \gtrsim 10^4 M_{\odot}$  and  $T \lesssim 100$  Myr in nearby ( $\lesssim 10$  Mpc) galaxies. PZMG10 used the ratio of the age of the stars over the crossing-time of the stars in the cluster,  $T_{\text{cr}}$ , to distinguish star clusters from associations, where the boundary

was set at unity\*. We refer to this ratio as the dynamical age, or  $\Pi = \text{Age}/T_{\text{cr}}$ .

The boundary at  $\Pi = 1$  is explicitly based on the distinction between bound and unbound agglomerates. For expanding objects  $\Pi < 1$ ; the radius increases roughly proportionally with age and  $T_{\text{cr}}$  therefore also increases. For bound objects  $\Pi > 1$ ; we observe that, to first order,  $R_{\text{eff}}$  and the crossing time remain roughly constant with time. A schematic view of the evolution of  $\Pi$  as a function of age for star clusters and associations is shown in Fig. 1.

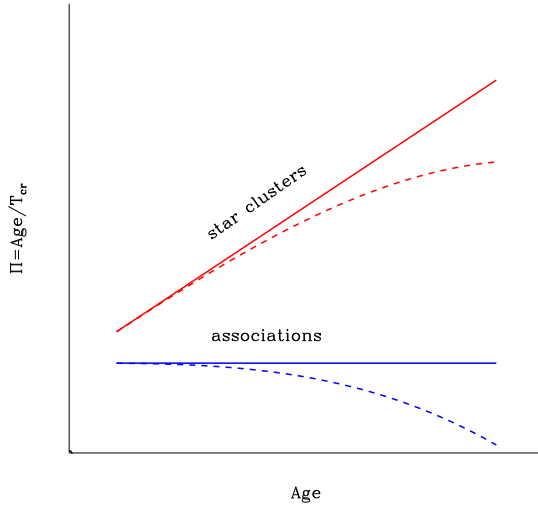
Here we define the crossing time in terms of empirical cluster parameters that are relatively straightforward to determine

$$T_{\text{cr}} \equiv 10 \left( \frac{R_{\text{eff}}^3}{GM} \right)^{1/2}, \quad (1)$$

where  $G$  is the gravitational constant. This definition is equivalent to equation (11) of PZMG10 apart from a factor  $2^{3/2}$  to define the crossing time in terms of diameter instead of radius (see footnote 1). A factor  $(4/3 \times 16/[3\pi])^{3/2} \approx 3.4$  was used to convert the virial radius to  $R_{\text{eff}}$ . Note that we assume a Plummer density profile and that light traces mass.

Equation (1) is valid for systems in virial equilibrium. A more general definition of  $T_{\text{cr}}$  includes the root-mean square velocity dispersion of the stars ( $T_{\text{cr}} \propto R_{\text{eff}}/\sigma$ ) which is available for fewer agglomerates and at young ages the measured  $\sigma$  can be higher than the virial motion of the stars because of orbital motions of multiples (Gieles, Sana & Portegies Zwart 2010). If unbound associations expand with a constant velocity then  $T_{\text{cr}} \propto \text{Age}$  and

\* In fact PZMG10 used the ratio  $\text{age}/T_{\text{dyn}} = 3$  as the boundary, where  $T_{\text{dyn}}$  is the dynamical time-scale of the cluster and  $T_{\text{cr}}/T_{\text{dyn}} = 2\sqrt{2} \approx 2.8$  for clusters in virial equilibrium.

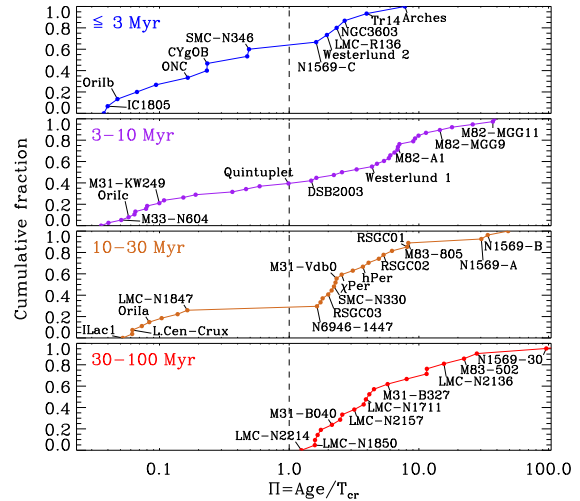


**Figure 1.** Schematic representation of the evolution of the dynamical age  $\Pi$  for star clusters (top lines) and associations (bottom lines). Two evolutionary tracks are shown for each. The dashed line for clusters (top) illustrates the effect of dynamical expansion (Gieles et al. 2010) on  $\Pi$ , whereas the solid curve is drawn assuming that the cluster radius does not change with time. The full line for associations shows how  $\Pi$  evolves when  $T_{\text{cr}}$  would be derived from a measured velocity dispersion ( $T_{\text{cr}} \propto R_{\text{eff}}/\sigma$ , with  $\sigma = \text{constant}$ ), whereas the dashed lines shows the evolution of  $\Pi$  when equation (1) is used to approximate  $T_{\text{cr}}$ .

$\Pi = \text{constant}$  (full line for associations in Fig. 1). By using equation (1), which assumes virial equilibrium, we thus overestimate the increase of  $T_{\text{cr}}$  (underestimates  $\Pi$  at older ages) of unbound associations thereby enlarging the difference in  $\Pi$  of bound and unbound systems (dashed line for associations in Fig. 1). This definition, therefore, facilitates in making the distinction.

In Fig. 2 we show the cumulative distribution of all objects in different age bins. The top panel shows the (cumulative) distribution of  $\Pi$  for the youngest age bin. This is a continuous distribution from  $\Pi \sim 0.03$  (i.e. associations) to  $\Pi \sim 10$  (i.e. star clusters). A similar result was recently obtained for the surface density distribution of young stellar objects in the solar neighbourhood (Bressert et al. 2010). There seems not to be a distinct mode of star cluster formation, but rather a smooth transition between star clusters and associations, which in turn can be interpreted as a smooth transition between bound and unbound objects.

The bottom panel shows that the oldest agglomerates all have  $\Pi \gtrsim 1$ , which according to our definition are bound star clusters. In this age bin there are several LMC and M31 star clusters with  $\Pi$  only slightly larger than one. This could be because most of these clusters have rather shallow light profiles which makes  $R_{\text{eff}}$  large compared to the core radius (PZMG10). But it can also be that these objects are only weakly bound. The intermediate age curves contain both associations and star clusters. If we interpret the curves for the different age bins as an evolutionary sequence then a distinct gap develops between star clusters and associations around  $\sim 10$  Myr at a value of  $\Pi \approx 1$ . At older ages an observer should be able to make an unambiguous distinction between an (unbound) association and a (bound) star cluster using this straight-forward method. For younger ages the distributions are not separated at  $\Pi = 1$  but for the youngest (continuous) distribution it still offers a good qualitative discrimination, as can be noted from the labels of several well known star clusters and associations. The exact fraction of the



**Figure 2.** Cumulative distributions of  $\Pi$  for nearby ( $\lesssim 10$  Mpc) stellar agglomerates (data from the compilation of PZMG10). The agglomerates are separated in four distinct age bin, with the age boundaries are indicated in the panels. Several star clusters and associations are identified by their common name. The vertical dashed line indicates the boundary value  $\Pi = 1$ .

newborn stars that ends up in bound star cluster can depend on environment (e.g. Elmegreen 2008). According to the definition of  $\Pi$  all agglomerates have  $\Pi = 0$  when they form so it is not very meaningful to classify objects when the star formation process is still ongoing (see also Bressert et al. 2010).

Our definition of the dynamical age  $\Pi$  offers a dynamically motivated and practical classification of unbound associations and bound star clusters. It can be applied to Galactic and extra-galactic samples whenever estimates for masses, effective radii and ages are available.

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